Deposition Lab / Optics Fabrication

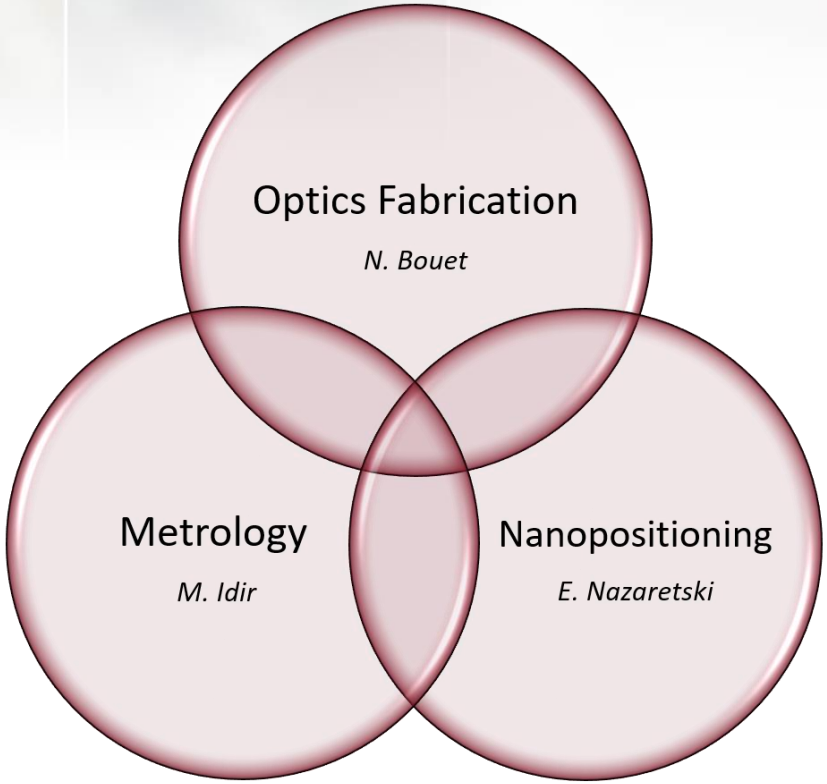
Nathalie Bouet

Beamline Engineering Meeting – March 26th, 2019

U.S. DEPARTMENT OF ENERGY | Office of Science
BROOKHAVEN NATIONAL LABORATORY

Optics Fabrication group

From left to right:
Abram Ledbetter (post-doc)
Matthew Vescovi (technician)
Nathalie Bouet (scientist)
Juan Zhou (scientific associate)



2010 BNL Engineering Award
2015 R&D 100 award in collab with LBNL, ANL and Abeam Technologies
2016 R&D 100 award in collab with NSLS-II nanopositioning team and HXN beamline
2016 Microscopy Today innovation award in collab with NSLS-II nanopositioning team and HXN
US patents 9,153,453 and 9,875,821

Collaborators

Optics and Metrology group

- Juan Zhou
- Matthew Vescovi
- Abram Ledbetter
- Evgeni Nazaretski
- Weihe Xu
- Wei Xu
- Dennis Kuhne
- Mourad Idir
- Lei Huang
- Tianyi Wang

HXN beamline – MLL R&D

- Yong Chu
- Hanfei Yan
- Xiaojing Huang

Many NSLS-II scientists …

- Elio Vescovo
- Kon Kaznatcheev
- Claudio Mazzoli
- Eric Dooryhee
- Sanjit Ghose
- Ignace Jarrige
- Valentina Bisogni
- Joe Dvorak
- Pete Siddons
- Lutz Wiegart
- Andrei Fluerasu
- Oleg Chubar…

APS-ANL

- Raymond Conley
- Albert Macrander
- Jorg Maser
- Michael Wojcik
- Deming Shu

ALS- LBNL

- Valeriy V. Yashchuk

Fraunhofer IWS Dresden

- Adam Kubec

Accustrata, Inc.

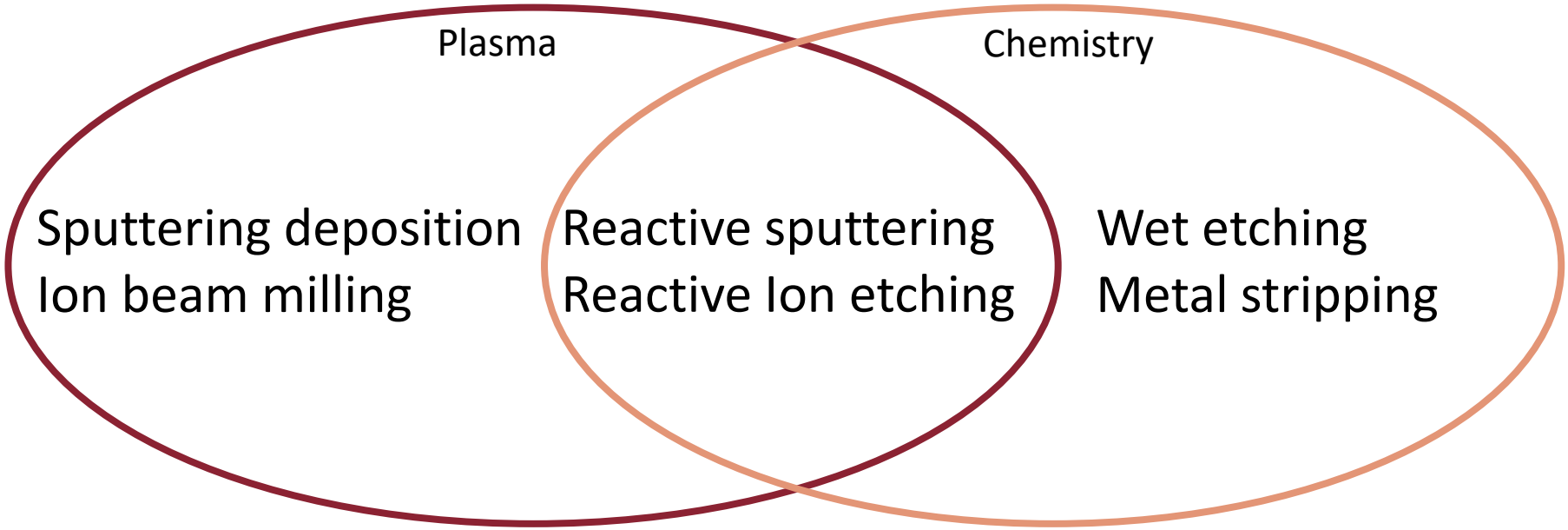
- George Atanasoff
- Christopher Metting
- Hasso Von Bredow

Optics fabrication at NSLS-II

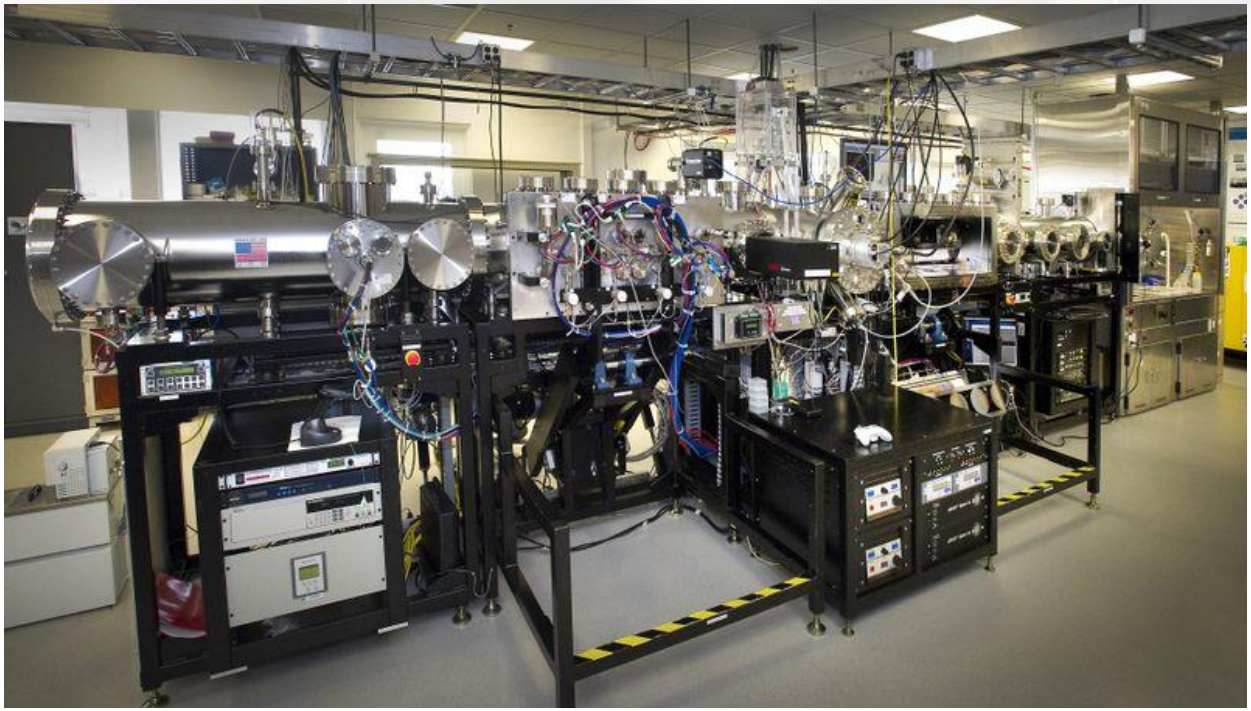
- Using either additive or subtractive processes

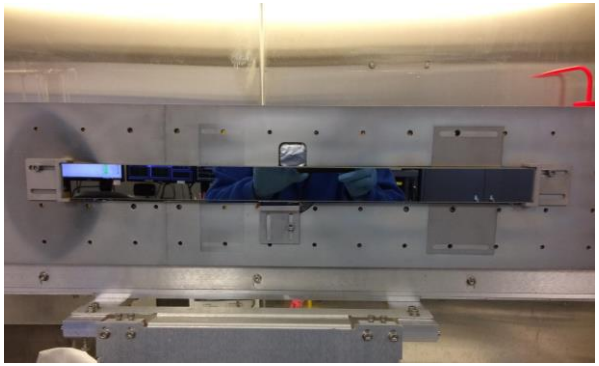
Material deposition Material removal

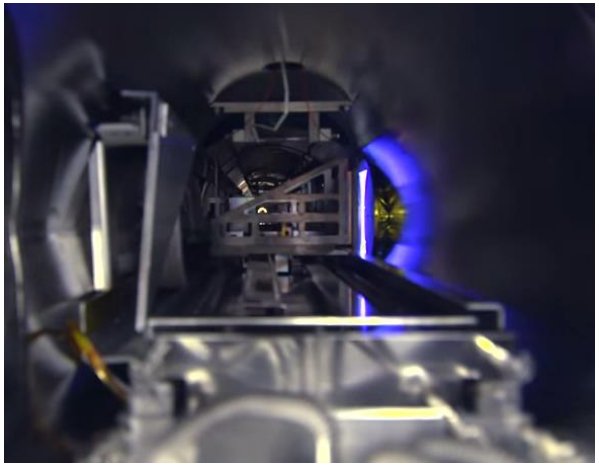
- Expertise in plasma and chemistry based techniques



Deposition Lab

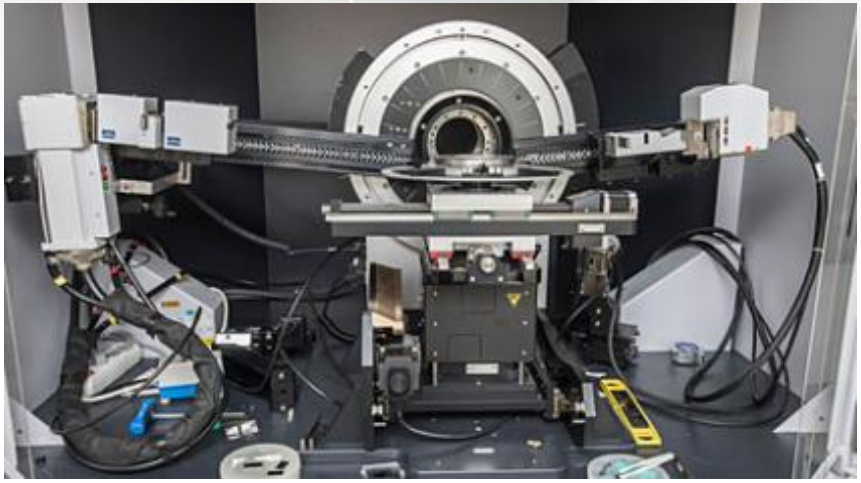


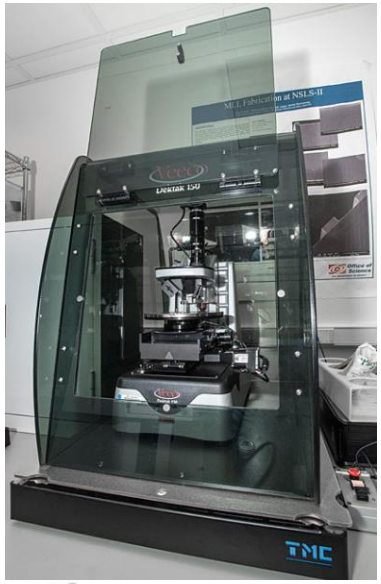




9 DC Sputtering guns
Linear travel
Sequential cathodes activation
Reactive sputtering possible
Ion gun – capable of handling gas mixtures
Base pressure ~ 8 x 10^{-8}Torr

Characterization tools and etching lab



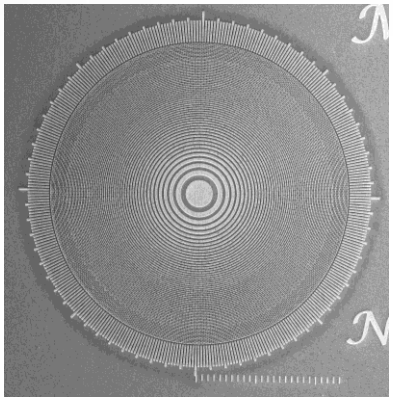


Multilayer Laue lenses R&D

High resolution nanofocusing optics for hard XR

MLL propose a solution to **overcome the aspect ratio challenge of ZP for hard X-ray** by creating the zone structure

Fabricated via **deposition of depth graded multilayer** obeying the ZP law **and further sectioning to the desired section depth**



- **Zone structure created via** deposition of **depth graded multilayer obeying the ZP law**
  - → several thousands of layers to be deposited
  - → total film thickness of tens of microns
- Based on thin film deposition techniques capabilities
  - → **1nm zone/layer thickness feasible**
- Virtually **no limit on aspect ratio** (thinnest zone width versus section depth) → Usable for hard X-ray nanofocusing

Multilayer Laue lenses (MLLs)

Full optics fabrication, metrology & testing in house

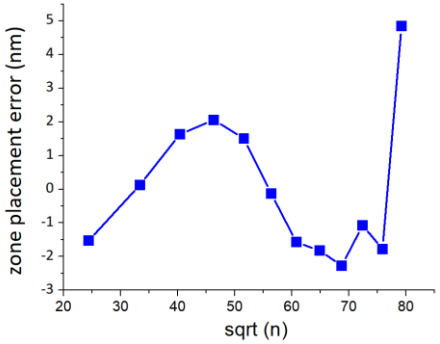
Deposition

Thousands of layers ~ 5000-8000

ML up to 100um thick

Flat & Wedged geometries

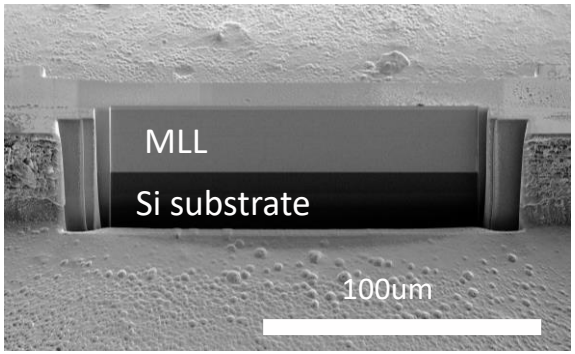
Accuracy of +/- 5nm over 43um



Sectioning

via Manual polishing + FIB or RIE +FIB

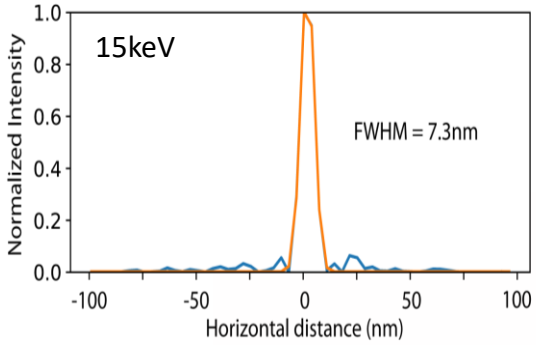
Section depth typically 5 to 15um for 10-20keV

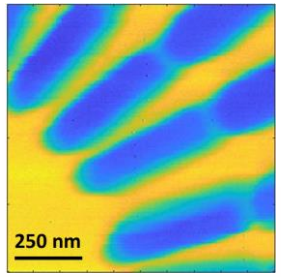


US patent 9,153,453

Optics testing

at HXN beamline

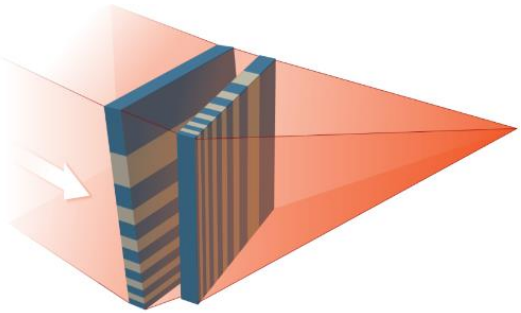




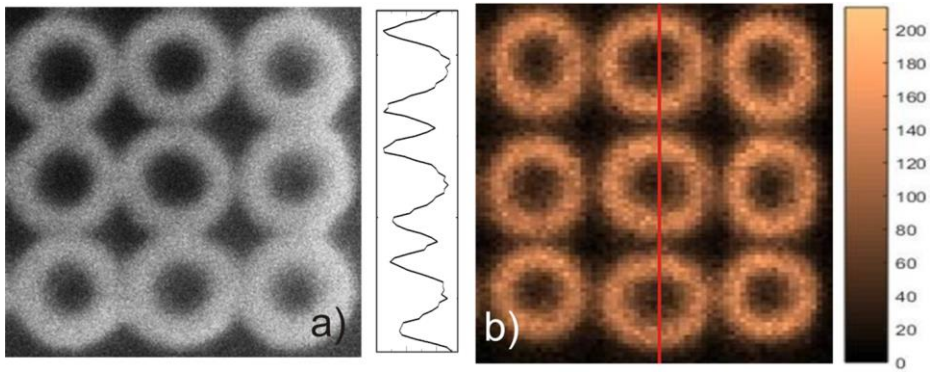
STXM

Optics integrated at Hard Xray Nanoprobe (HXN) beamline for users experiments

2D focusing achieved
by using
2 crossed MLL



Pt circles are 80 nm diameter and 20 nm line width



SEM

XRF (Pt L-edge)
12keV
Exposure time 0.2s
5nm per pixel

Nazaretski et al., AIP Conf. Proc. 1764 (2016)

13 x 13 nm^2 point focus offered to NSLS-II users at HXN using a 43um and a 53um MLLs

Beamline support - Multilayers and thin films coatings

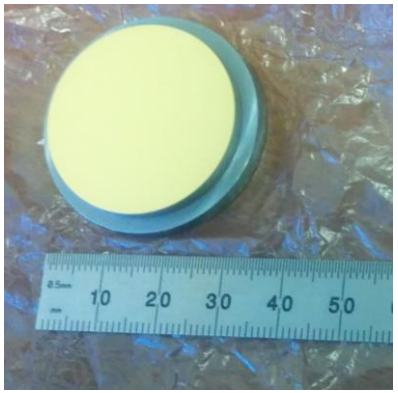
multilayers

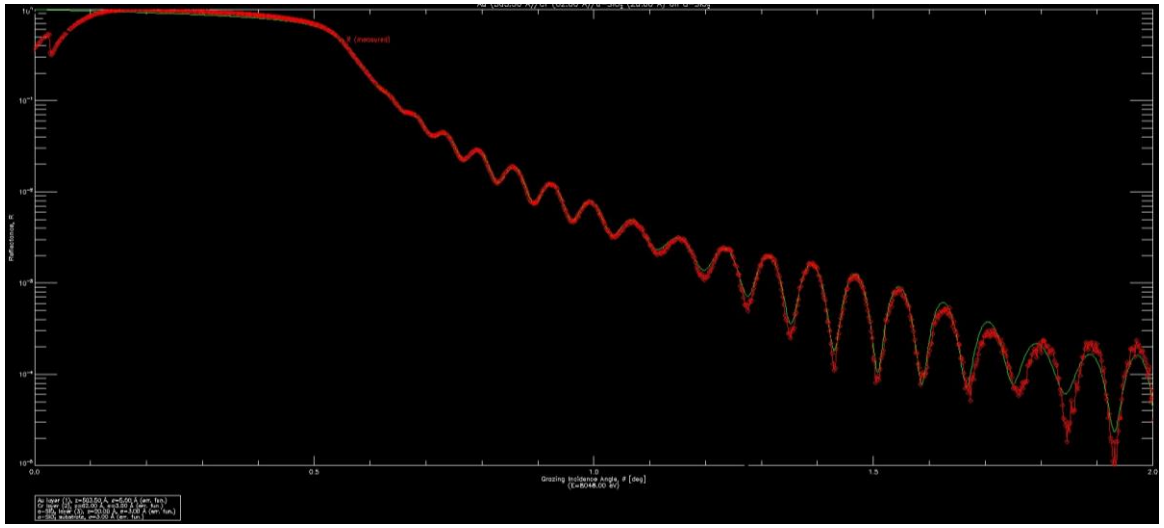
thin films

multi-stripes

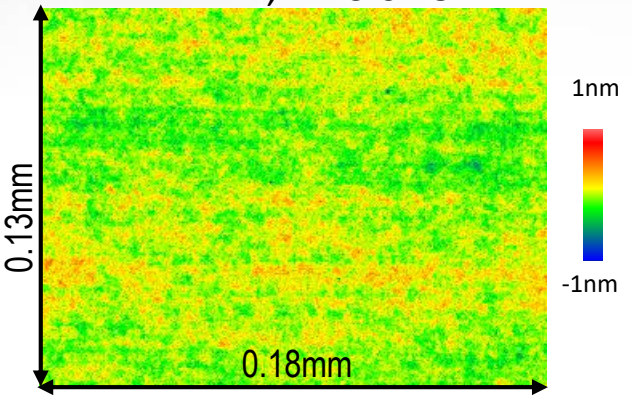
Example : gold coatings

Coatings of different substrates from 10mm to 100mm
Thicknesses from few nm to 1 micron
for diverse applications

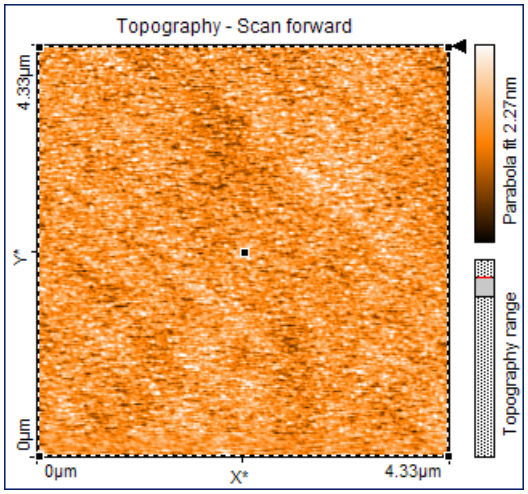




PV: 1.72nm, RMS:0.15nm



after sys error and best plane subtraction, ; ZYGO NewView x20 objective, x2 zoom lens

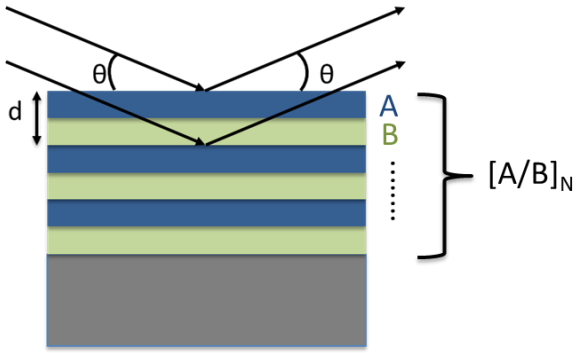


AFM roughness (rms) =0.3nm

Multilayers coatings

Example of multilayers grown for NSLS-II ESM and SIX beamlines

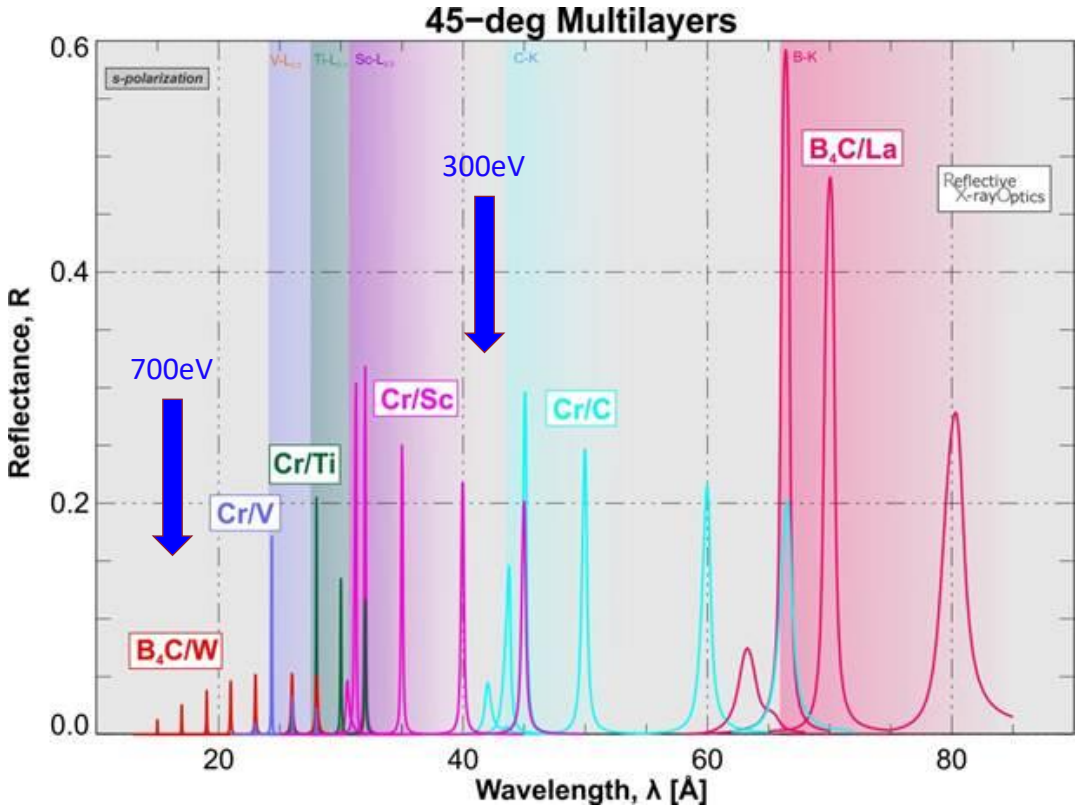
Multilayer structure



Bragg peaks: $m\,\lambda = 2\,d\,\sqrt{n^2 - cos^2\theta}$

Bandwidth: $\Delta E/E \sim 1/N$

Multilayers used as monochromators to characterize their undulators and help with the alignment of beamline elements.

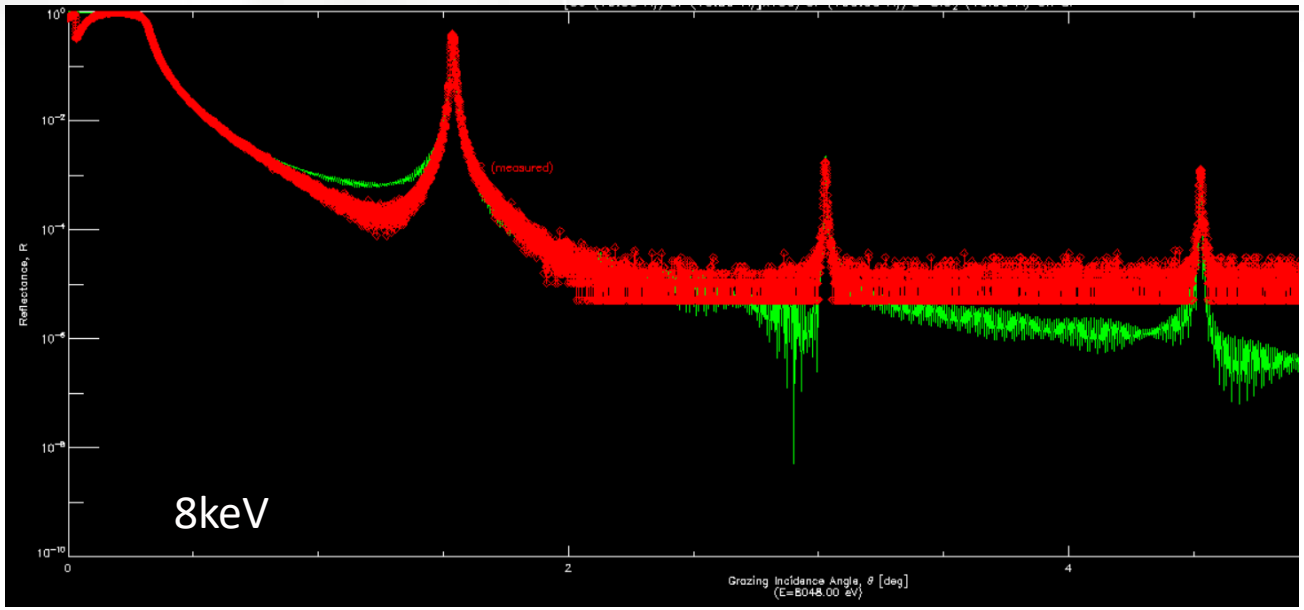


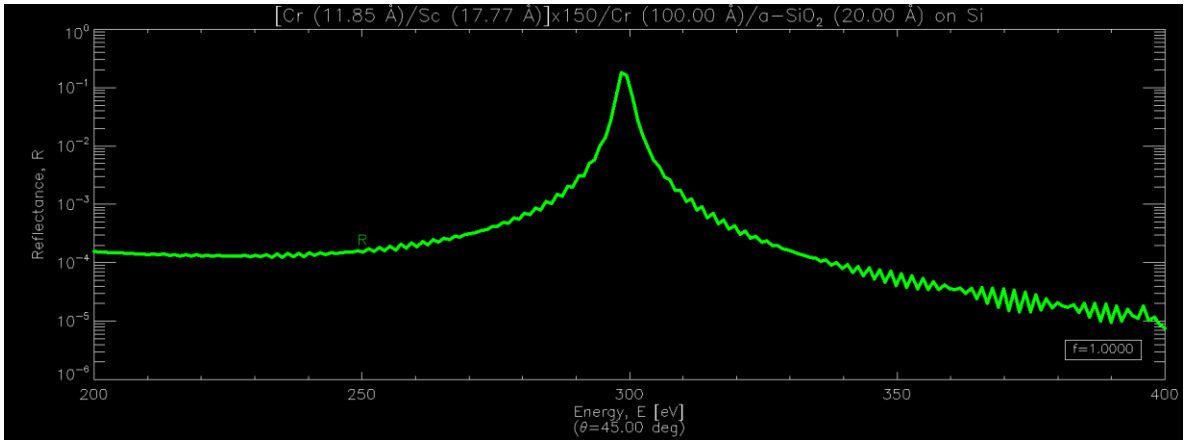
Source : http://www.rxollc.com

DiagOn reference :
K. Desjardins, AIP Conf. Proc. ***879****, 1101 (2007)*

300eV multilayers – 45° incidence

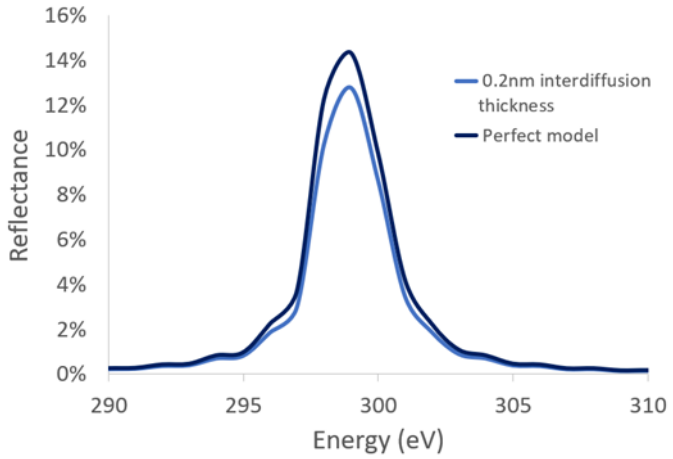
Cr/Sc
150 bilayers, d=2.96nm
Si substrate





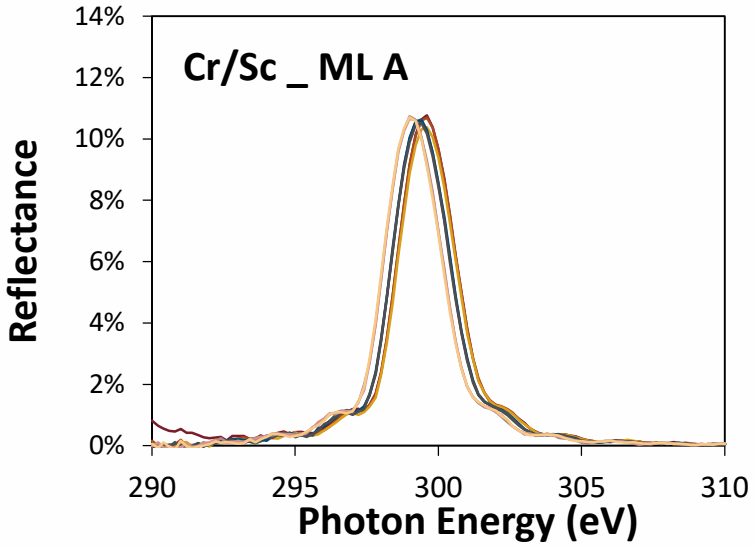
Optics testing of the multilayers @ 45° incidence

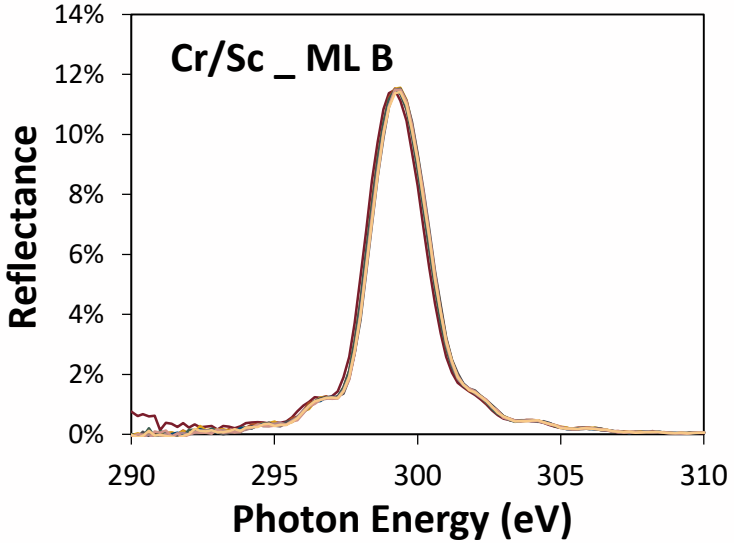
Cr/Sc
150 bilayers
d=2.96nm
Si substrate



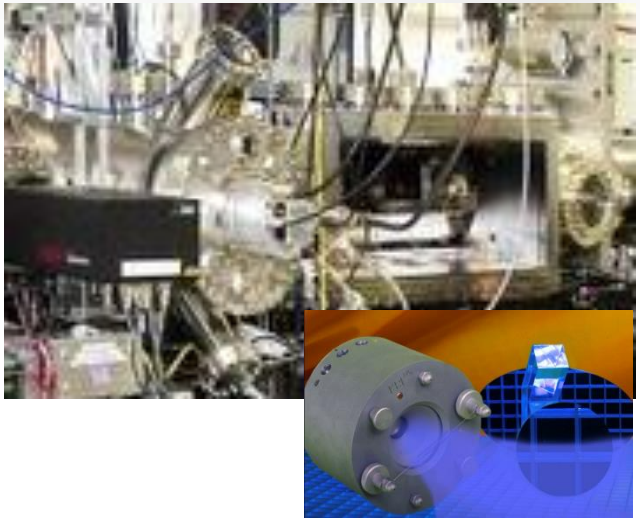
Simulations using CXRO website

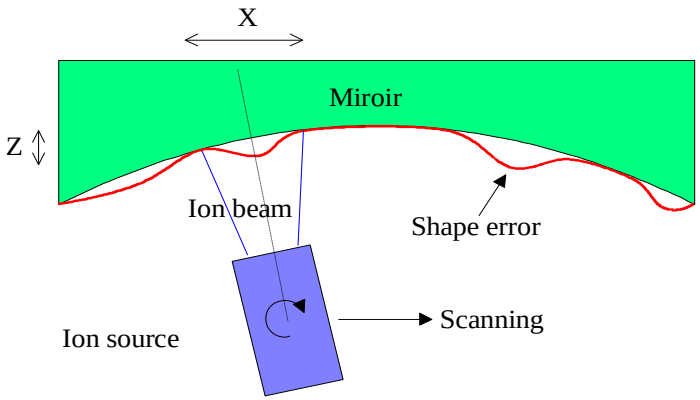
MLs tested at ALS (BL 6.3.2)
at 45 deg incidence by E. Gullikson





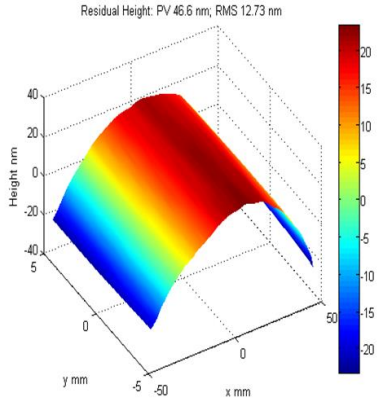
Ion beam figuring – collab with Metrology





Plane sample #1

Promising proof-of-principle first results



λ/14 ~ 300$

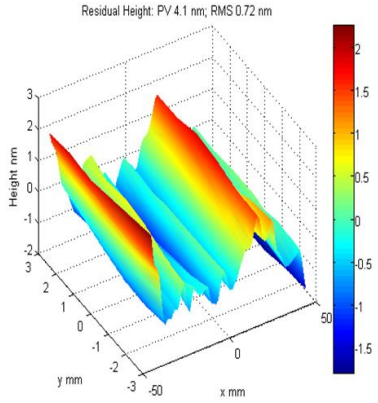
~ 44 nm PV
RMS: 15 nm

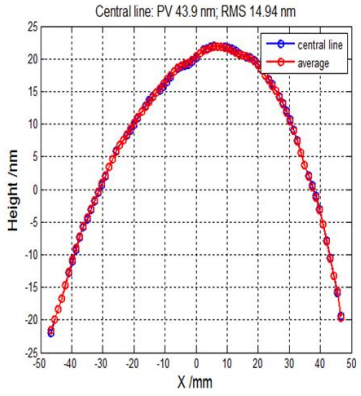
1D IBF

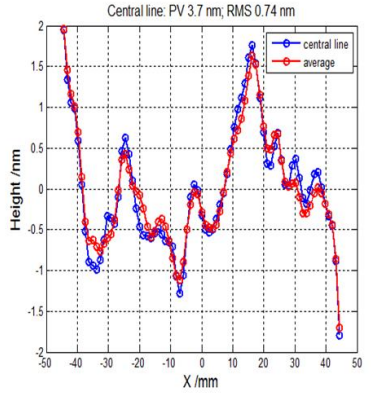
9 minutes

~ 3.7 nm PV
RMS: 0.74 nm

λ/171 ~ 3000$







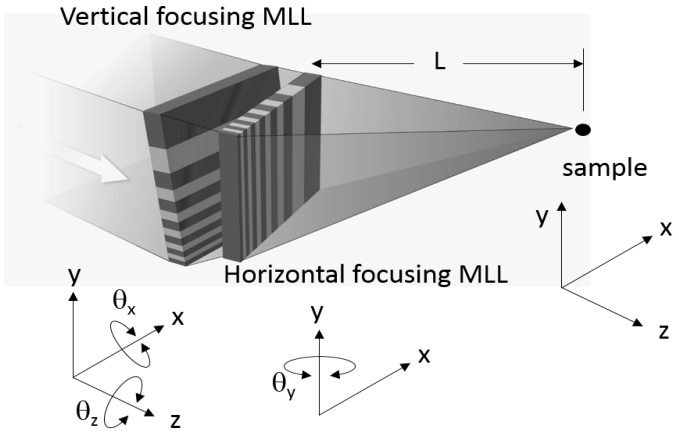
Review of Scientific Instruments 86, 105120 (2015)
J. Synchrotron Rad. 23, 182 (2016)
J. Synchrotron Rad. 23, 1087 (2016)

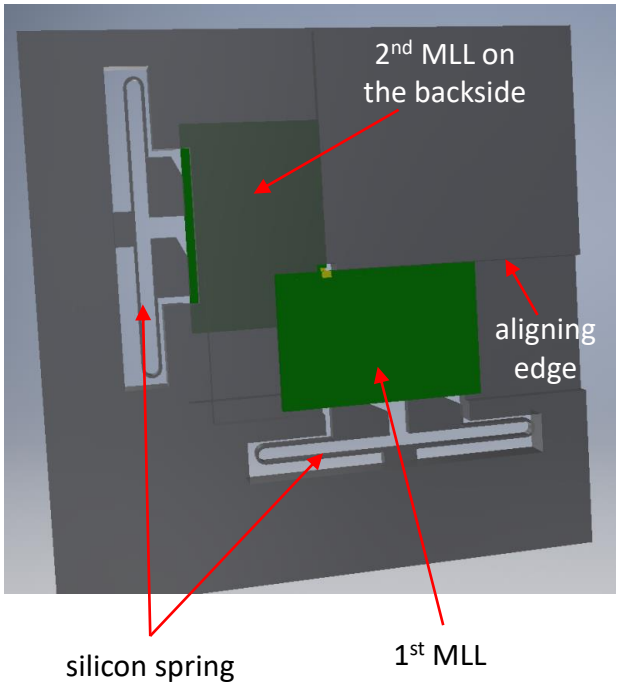
New dedicated chamber under procurement

Bonded MLLs – collab with Nanopositioning

Monolithic MLL as an alternative to complex alignment procedure

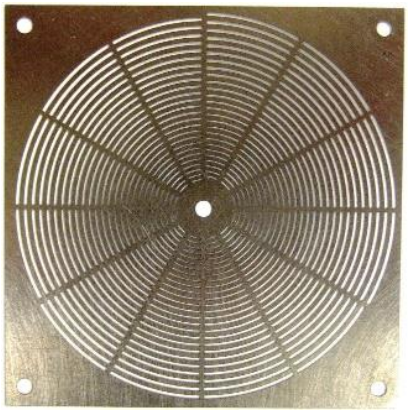
- Alignment of two linear MLL optics is complex
- Stringent requirements for accuracy of alignment and stability of the microscope



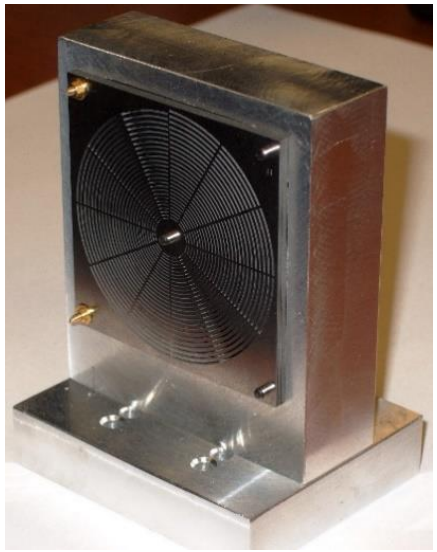


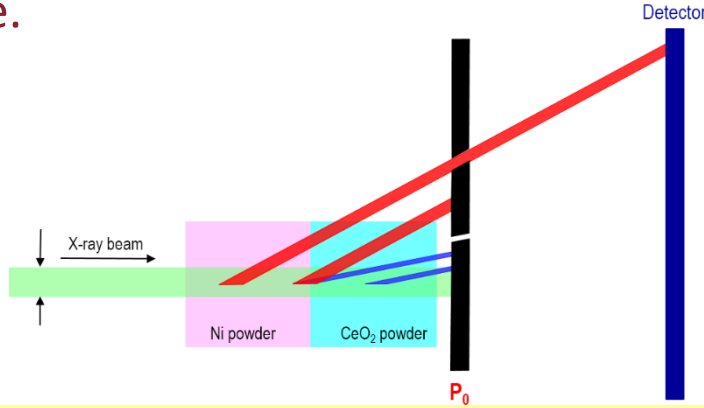
Conical Slit fabrication for Probing Buried Volumes for Dynamic Measurements of Heterogeneous Materials – collab with XPD beamline

Goal : Implementation of a conical/spiral slit which will allow diffracted rays to be transmitted if and only if they originate from a three dimensional gauge volume, defined by the beam size and slit opening size.

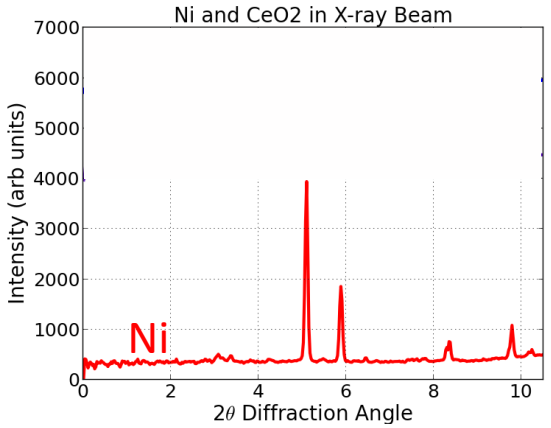


US patent 9,875,821





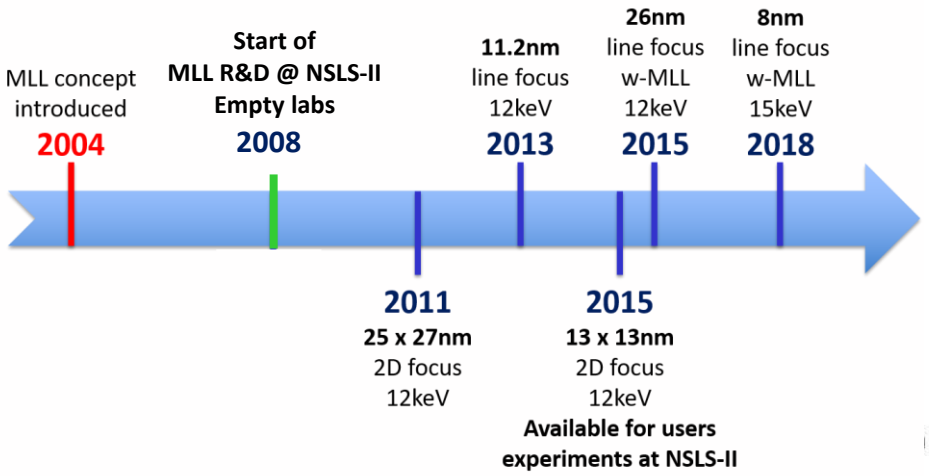
Measure of integrated intensity as the slit gauge volume is translated from a Ni powder to a CeO_2 powder



Fabrication using laser cutting and reactive ion etching → Fabrication methods allowing high accuracy

Summary

- Capabilities of deposition of high quality films at NSLS-II
  - Simple coatings (Au, Pt, Rh…)
  - Multilayers
  - MLLs
- Very successful R&D on MLL optics with a lot of developments in the past years leading to :
  - Growth of high quality multilayers
  - Demonstration that large aperture MLLs optics are possible
  - High spatial resolution and high efficiency can be achieved with wedged MLLs



Summary

- Application of our knowledge on fabrication processes to other optical components and new techniques development
  - Bonded MLLs
  - Ion Beam figuring
  - Spider web slits
  - Growth monitoring instrumentation developments …